COMPLIANT, STRAIN TOLERANT INTERCONNECTS FOR SOLID OXIDE FUEL CELL STACK

CROSS-REFERENCE TO RELATED CASES

[0001] This application claims the benefit of earlier-filed provisional patent applications entitled, "Compliant, Strain Tolerant Interconnects and Seals for Solid Oxide Fuel Cell Stack," Application No. 60/444,025, filed January 31, 2003, and "Compliant Interconnects and Seals for Solid Oxide Fuel Cell Stack," Application No. 60/454,899, filed March 14, 2003, and is a continuation-in-part of U.S. Application No. 10/307,008, Filed November 27, 2002.

BACKGROUND OF THE INVENTION

[0002] The invention relates to solid oxide fuel cell (SOFC) stacks and, more particularly, to an interconnect that enhances the lifetime of SOFC stacks.

[0003] A fuel cell is a device which electrochemically reacts a fuel with an oxidant to generate a direct current. The fuel cell typically includes a cathode, an electrolyte and an anode, with the electrolyte being a non-porous material positioned between the cathode and anode materials. In order to achieve desired voltage levels, such fuel cells are typically connected together using interconnects or bipolar plates to form a stack, or fuel cell stack, through which fuel and oxidant fluids are passed. Electrochemical conversion occurs, with the fuel being electrochemically reacted with the oxidant, to produce a DC electrical output.

[0004] The basic and most important requirements for the interconnect materials on the cathode side of a SOFC stack are sufficient oxidation and corrosion resistance in air at the stack operating temperatures; sufficient electron conductance; and close matching of thermal expansion behavior to that of the ceramic cell. In the case of metallic interconnects, the requirement of sufficient electron conductance is essentially equivalent to the electron conductance of the oxide scale that forms on the metal surface because the oxide scale tends to be the limiting resistance. Currently, the lack of stable, long-life (>40,000 hours), metallic interconnects for the cathode side of the stack, is a serious weakness of planar solid oxide fuel cells, because existing metal alloys cannot meet the thermal expansion, oxidation resistance, and electron conductance requirements simultaneously.

[0005] Cathode interconnect materials that have been used to date include perovskite-based ceramics, e.g. lanthanum chromite, high temperature chromium-based alloys or composites thereof, and nickel-based alloys or intermetallics have been used typically for cells operating in the 800-1000 °C range.

[0006] The prior art on ceramic-based interconnects such as lanthanum chromite indicates that this material exhibits both usable high temperature conductivity and thermal expansion behavior that matches the cell. However the ceramic is very expensive, has low toughness and is difficult to manufacture as a suitable interconnector. Chromium-based interconnector materials have similar drawbacks.

[0007] Lower operating temperatures, (650-800°C) with planar anode-supported cells, permit use of lower cost materials such as ferritic stainless steels that have a better coefficient of thermal expansion (CTE) match with the cell than Ni-based alloys. Commercial grades of ferritic steels may have suitable oxidation resistance at temperatures less than about 600°C or for short lifetimes, but do not have the required oxidation resistance to last for 40,000 hours, or longer, due to the increasing ohmic resistance across the oxide scale with time under load.

[0008] The majority of prior art on these issues has attempted to prevent or ameliorate the degradation caused by oxide scale. Specifically, to take advantage of the lower cost and favorable CTE of ferritic steels, minor alloying additions and/or surface coatings have been researched to improve the oxidation resistance and conductivity. Certain elements such as Mn appear beneficial in forming manganese chromite which increases the conductivity of the oxide scale, but more data is needed to determine whether both conductivity and oxidation resistance are sufficient for long-term applications. However, elements known to improve oxidation resistance, such as Al and Si, also tend to disadvantageously reduce the oxide conductivity and increase the CTE of the alloy. In Fe-Cr-Al-Y type steels, excellent oxidation performance is traded for the high resistivity of the resulting alumina film. Hence, the current state-of-the-art with regard to low cost Fe-Cr-based steels, has not fully resolved the long-term contact and oxidation issues.

[0009] Other materials, such as Ni-Cr or Ni-Cr-Fe-based alloys, while having good oxidation/corrosion resistance by design, typically have CTE values in the 15-18 parts per million (ppm)/°C compared to the about 12 ppm/°C of ferritic steels which better match the CTE of the ceramic cell.

[0010] Preferential removal of the oxide and/or coating/doping of the alloy surface with noble metals such as Ag, Au, Pt, Pd, and Rh has been used to mitigate conductivity loss by reducing oxygen diffusion into the contact points of the interconnect, but noble metals are too costly to use in power plants and commercial applications.

[0011] The oxidation resistance is clearly a concern on the cathode/oxidant side of the interconnect. However, the partial pressure of oxygen at the anode/fuel electrode may also be high enough to form Cr_2O_3 and the oxide may be even thicker (viz. the presence of electrochemically formed water) than on the cathode side of the interconnect, so the resistivity of the interconnect may increase on both sides. The construction materials on the anode side of the interconnect could be the same as the cathode, although prior art has shown that, in the case of a ferritic steel interconnect in contact with a nickel anodic contact, weld points that formed between the steel and the nickel still formed a thin electrically insulating Cr_2O_3 layer over time which degraded performance.

[0012] It is clear, from the above review of background art, that the need remains for a substantially improved interconnect between adjacent cells, whereby interface strains, caused by CTE mismatch during thermal cycling, are substantially eliminated, while the material provides long-term oxidation resistance and high electron conductance across the oxide scale.

[0013] It is therefore the primary object of the present invention to provide an interconnect or bipolar plate that meets the aforementioned needs.

[0014] Other objects and advantages of the present invention will appear hereinbelow.

SUMMARY OF THE INVENTION

[0015] In accordance with the present invention, the foregoing objects and advantages have been readily attained.

[0016] The present invention provides a solid oxide fuel cell design having a compliant porous interconnect which alleviates the thermal expansion mismatch stresses which are typically generated by higher thermal expansion oxidation resistant interconnect metals and/or alloys for the cathode.

[0017] The interconnect of the present invention advantageously allows for the use of higher thermal expansion oxidation resistant metals or alloys for the separator plate.

[0018] The interconnect of the present invention further advantageously allows for less stringent dimensional tolerances of the stack components since the interconnect is compliant in all three dimensions and permits displacement with minimal increase in stress to accommodate dimensional variations.

[0019] According to the invention, an interconnect is provided which comprises a compliant porous member, compliant in all three-dimensions and having first portions defining a separator plate contact zone and second portions spaced from said first portions and defining an electrode contact zone.

[0020] In further accordance with the invention, an interconnect assembly is provided for solid oxide fuel cells, which assembly comprisesa separator plate having two opposed surfaces; and at least one interconnect positioned adjacent to at least one of said two opposed surfaces and comprising a compliant porous member, compliant in all three-dimensions and having first portions defining a separator plate contact zone and second portions spaced from said first portions and defining an electrode contact zone.

[0021] Still further according to the invention, the interconnect assembly could be comprised of one or more layers, at least one of which is compliant as described herein. In this embodiment, the compliant layer may or may not be in contact with the separator plate or the electrodes.

[0022] Still further according to the invention, a solid oxide fuel cell assembly is provided which comprises a plurality of fuel cells arranged in a stack; and a plurality of interconnect assemblies positioned between adjacent cells of said stack, said interconnect assemblies comprising a separator plate having two opposed surfaces and at least one interconnect positioned adjacent to at least one of said two opposed surfaces and comprising a compliant porous member, compliant in all three dimensions and having first portions defining a separator plate contact zone and second portions spaced from said first portions and defining an electrode contact zone.

[0023] Particularly desirable configurations of the interconnect involve three-dimensional compliant superstructures made out of wire weaves or other compliant sub-structures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] A detailed description of preferred embodiments of the present invention follows, with reference to the attached drawings, wherein:

[0025] Figure 1 schematically illustrates a fuel cell stack assembly in accordance with the present invention;

[0026] Figure 2 schematically illustrates a portion of the fuel cell stack assembly of claim 1;

[0027] Figure 3 illustrates a preferred embodiment of an interconnect of the present invention;

[0028] Figures 4 and 5 illustrate another preferred embodiment of an interconnect of the present invention;

[0029] Figure 6 illustrates an alternate embodiment of an interconnect of the present invention;

[0030] Figure 7 illustrates an alternate embodiment of an interconnect of the present invention;

[0031] Figure 8 illustrates another alternate embodiment of an interconnect of the present invention;

Figure 9 illustrates a wire structure with compliance loops according to the invention; and

[0032] Figure 10 illustrates another preferred embodiment of an interconnect of the present invention.

DETAILED DESCRIPTION

[0033] The invention relates to a fuel cell assembly and, more particularly, to a solid oxide fuel cell (SOFC) stack having improved metallic interconnect which decouples the need for good coefficient of thermal expansion (CTE) match with other stack components from other requirements such as oxidation resistance and oxide scale electron conductance.

[0034] The invention relates further to a fuel cell stack and, more particularly, to a solid oxide fuel cell stack having an improved interconnect, whereby stresses due to difference in thermal expansion coefficient between adjacent fuel cell stack components, and specifically between the cathode or anode interconnect and adjacent fuel cell or separator plate, are minimized so as to provide for enhanced fuel cell stack lifetime and robustness under steady state and thermal cycling.

[0035] Reduction in stress is accomplished through a compliant interconnect superstructure provided from a compliant sub-structure, wherein the interconnect superstructure is provided having contours so as to define spaced contact zones for contacting a separator plate on one side and an electrode of a fuel cell on the other side, and the sub-structure is provided by highly compliant pre-buckled architecture as present in a wire mesh. The combination of the two, compliant superstructure and compliant sub-structure, providing spaced contact zones in accordance with the present invention advantageously allows for CTE mismatch between various components of the stack without subjecting such components, or bonds or other types of connection therebetween, to excessive stress, while improving fluid flow and electrical functionality of the fuel cell.

[0036] The compliant interconnects described herein are designed such that high values of both in-plane and out-of-plane compliance are achieved. One skilled in the art will recognize that any such interconnect that provides for acceptable levels of either in-plane compliance or out-of-plane compliance, or both, will be within the broad scope of the invention. Preferably, the compliant superstructure is compliant in at least three orthogonal axes, and is compliant with respect to a load applied from any direction. Various approaches to achieve this include wire weave based superstructures as described above, 3-dimensional knitted wire structures, helical coils in various configurations including slanted helical coils provided by pre-buckled highly compliant sub-structures, wires with in-built highly compliant compliance loops, similar interconnects made from sheet metal, foil, foam, or expanded metals formed into superstructures, etc. Preferred compliance values of the interconnects are $5x10^{-6}$ mm^2/N (in strain/stress units) and higher for typical interconnects at room temperature. More preferred compliancy values are $5x10^{-5}$ mm^2/N and higher for typical interconnects. Most preferred compliancy values are $5x10^{-4}$ mm^2/N and higher for typical interconnects, but one of ordinary skill in the art will recognize that other compliancy values can be acceptable and are within the scope of the invention.

[0037] Turning to Figure 1, a fuel cell stack assembly 10 in accordance with the present invention is schematically illustrated. Assembly 10 preferably includes a plurality of fuel cells 12 arranged in a stack with bipolar plates 14 positioned therebetween.

[0038] Fuel cells 12 typically include an electrolyte 16, a cathode layer 18 positioned on one side of electrolyte 16, and an anode layer 20 positioned on the other side of electrolyte 16. Bonding or current carrying layers 22 may be used on the two sides.

[0039] Bipolar plate 14 in accordance with the present invention advantageously includes a separator plate 24 having a cathode facing surface 26 and an anode facing surface 28, a cathode-side interconnect 30 positioned between cathode facing surface 26 and a cathode layer 18 (or layer 22) of an adjacent fuel cell 12, and an anode-side interconnect 32 positioned between anode facing surface 28 and an anode layer 20 (or layer 22) of an adjacent fuel cell 12. Interconnects 30, 32 are advantageously provided of an electron conducting material and are in electrical communication with separator plate 24.

[0040] Referring to Figure 2, a particular aspect of the present invention is the design of cathode-side and anode-side interconnects 30, 32, wherein the interconnects are provided as a sheet of woven wire material formed to have a plurality of first portions 34 or 38 defining an electrode contact zone, and a plurality of second portions 36 defining a separator plate contact zone which is spaced from the electrode contact zone.

[0041] Still referring to Figure 2, interconnects 30, 32 in accordance with the present invention, especially cathode-side interconnect 30, consists of compliant sub-structure, preferably wire weaves, material as described above which is formed, for example through die stamping, rolling, bending or the like, to have a three-dimensional superstructure defining first and second portions 34, 36.

[0042] The compliant wire weave sub-structure of interconnects 30, 32 in accordance with the present invention is advantageously a wire weave such as that illustrated in Figure 2, which advantageously provides a pre-buckled architecture that increases compliance of interconnect 30, 32. This compliance allows for movement or deflection without stressing of first portions 34, relative to second portions 36 during thermal cycling and the like, which advantageously serves to eliminate stresses caused by CTE mismatch between various components. The compliant interconnects formed from such

sub-structures and superstructures also advantageously allows for movement between first portion 34 with respect to second portion 36 without stressing during assembly, thereby permitting larger dimensional tolerance variations.

[0043] The wire weave as shown in Figure 2 may include a first plurality of wires or substructures disposed in one direction, and a second plurality of wires or substructures disposed in a different direction, so as to define a woven wire structure which is porous to operating fuel cell gaseous materials and compliant as desired in different directions, in accordance with the present invention.

[0044] Figure 3 shows a perspective view of an interconnect 30, 32 to further illustrate a preferred sub-structure and superstructure thereof.

[0045] Figures 1, 2 and 3 illustrate interconnects 30, 32 as members having a substantially sinusoidal cross section, wherein peaks 38 on one side of a centerline 40 define the electrode contact zone, and peaks 42 on the other side of centerline 40 define the separator plate contact zone. In accordance with a preferred aspect of the present invention, and as illustrated in Figure 3, the undulating or vertically contoured shape of interconnect 30, 32 extends in the transverse direction to the cross section illustrated in Figures 1 and 2 so as to define a series of spaced peaks 38, 42, each extending in opposite directions from centerline 40, so as to define the spaced contact zones discussed above.

[0046] It should of course be appreciated that other architectures could be provided for interconnects 30, 32, within the broad scope of the present invention, which could equally provide for the spaced contact zones connected by compliant members which provide for advantageous reduction in stresses between components as desired in accordance with the present invention.

[0047] Figure 4, for example, illustrates interconnect 30, 32 with compliant superstructures shaped in a substantially orthogonal, for example square or retangular channel pattern, made from a compliant sub-structure material, preferably wire weave, wherein the interconnects form spaced contact zones in the cross sectional view. Figure 4 further illustrates a preferred wire weave structure according to the invention. Figure 5 shows a perspective view of such an interconnect 30, 32 on bipolar plate 14.

[0048] Another example, Figure 6, shows a substantially square channeled superstructure interconnect 30, 32 with spaced contact zones present in both the cross sectional and the transverse direction.

[0049] Another example, Figure 7, shows a substantially trapezoidal superstructure

interconnect 30, 32 made from compliant sub-structures.

[0050] Another example, Figure 8, illustrates a superstructure interconnect 30, 32 made into a circular or a helical, preferably slanted, structure wherein a compliant sub-structure such as a pre-buckled wire or wire weave forms the three-dimensional superstructure.

[0051] Figure 9 illustrates an embodiment wherein wires 52 are provided with compliance loops 54 as described above. This structure serves to enhance the ability of the wire to resiliently deform as needed to respond to different CTE, and also to provide desired manufacturing tolerances. This compliance loop structure can be incorporated into the substructure and/or the superstructure of the interconnect of the present invention.

[0052] Figure 10 shows a substantially hour-glass shaped superstructure interconnect 30, 32 made from compliant sub-structures.

[0053] Interconnect 30, 32 in these examples can be positioned between components of the stack in similar fashion to the embodiment described above in connection with Figures 1-4.

[0054] Clearly, those skilled in the art will realize that a large number of patterns and arrangements of such compliant sub-structures as well as superstructures exist, and are all within the broad scope of the present invention.

[0055] Different materials and architectures may be desirable for cathode-side interconnect 30 than for anode-side interconnect 32.

[0056] Cathode-side interconnect 30 is preferably provided having the architecture as described above and illustrated in Figures 1 and 2.

[0057] Anode-side interconnect 32 can advantageously be provided having the same architecture, or having a foam architecture defining foam cells which, themselves, define the contact zones for contact on one side with separator plate 24 and on the other side with the anode of a fuel cell 12.

[0058] Further, in the cathode environment, it is desirable to provide cathode-side interconnect 30 of an oxidation resistant conductive material, preferably of a material selected from the group consisting of selected stainless steels, stainless steel alloys and super-alloys comprising Ni-Cr-, Ni-Cr-Fe-, Fe-Cr-, Fe-Cr-Ni and Co-based alloys as well as Cr-based alloys and noble metal/alloys. Such super-alloys include HAYNES® alloy 230, HAYNES® alloy 230-W, and Hastelloy X, which have been found preferable in the present invention. Other materials include composites of at least 2 materials, for example

metals and ceramics containing any of the above mentioned metals and alloys. Another set of materials include noble metal coated super-alloys.

[0059] Anode-side interconnect 32 is advantageously provided of a material selected from the group consisting of Ni, Ni-Cu, Ni-Cr-, Ni-Cr-Fe-, Fe-Cr-, Fe-Cr-Ni and Co-based alloys as well as Cr-based alloys and noble metal/alloys and including such alloys coated with Ni, Cu or Ni-Cu as well as noble metals. Other materials include composites of metals and ceramics containing any of the above mentioned metals and alloys.

[0060] In accordance with the present invention, interconnects 30, 32 when provided having the configuration of Figures 1 and 2 preferably define a superstructure wherein peaks 38, 42 define a superstructure wavelength of between 0.1 mm and 100 mm, a superstructure amplitude of between 0.1 mm and 50 mm, and a superstructure periodicity which may be uniform or random.

[0061] Further, the wire weave sub-structure of interconnect 30, 32 in accordance with the present invention is preferably provided having a wire diameter of between 0.05 mm and 5 mm,a sub-structure weave wavelength of between 0.05 mm and 50 mm, a weave amplitude of between 0.05 mm and 50 mm, a weave pattern which may be square, plain, satin, twill or other patterns, and a weave periodicity which may be uniform or random.

[0062] In addition, the wire weave sub-structure of interconnect 30, 32 may be composed of wires of different diameters and/or alloys in different places to facilitate functionality.

[0063] In accordance with the present invention, separator plate 24 can advantageously be bonded to anode-side interconnect 32 and cathode-side interconnect 30 through various methods to produce high-strength interfaces therebetween. For example, such joints or components can be bonded, welded or brazed together, or can be secured together in other manners which would be well known to a person of ordinary skill in the art. Furthermore, it is within the broad scope of the present invention to position these components adjacent to each other without any bonding therebetween.

[0064] The wire weave sub-structure and three-dimensional superstructure of the interconnects in accordance with the present invention advantageously serves to alleviate stresses at the anode and cathode interfaces, and minimizes fracture of the interface and the cells themselves.

[0065] In further accordance with the present invention, and as illustrated in Figure 1, a compliant seal is further advantageously provided for sealing between edges of bipolar plate 14 and adjacent fuel cells 12.

[0066] In accordance with the present invention, the seal design is provided in the form of a rail or spacer 44 defining therein a groove 46, and a seal member 48 positioned in groove 46 and compressed between bipolar plate 14 and adjacent fuel cells 12 to provide the desired seal therebetween. A compression stop 50 is provided to control the amount of deflection of the compliant seals and to advantageously assemble compliant interconnects, compliant seals and all other elements of the stack.

[0067] In further accordance with the present invention, seal member 48 is advantageously provided as a compliant or compressible member formed from a suitable material, preferably alumina fibers. Alumina is most desirable in accordance with the present invention because alumina does not contaminate the fuel cell as do other seal materials which have conventionally been used, such as glass, glass-ceramics and the like.

[0068] Thus, in accordance with the present invention, seal member 48 is advantageously provided as compliant alumina fibers which can preferably be impregnated with another material selected so as to provide substantial gas impermeability of seal member 48 while nevertheless allowing for compliance or compressibility thereof.

[0069] The seal member 48 in accordance with the present invention can advantageously be impregnated with a material selected from the group consisting of zirconia, alumina, yttrium aluminum garnate, alumino-silicate and magnesium silicate ceramics, and similar oxides, and combinations thereof, and it is preferred that seal member 48 be provided so as to reduce permeability to gas.

[0070] Seal member 48 can advantageously be provided having a fiber architecture such as tows, yarns, fiber weave architecture and the like. Such architectures can be loaded with secondary particles within the fibers as discussed above so as to provide desired seal properties. Further, rail/spacer 44 and compression stop 50 is provided having a height and groove depth which are selected to provide for additional decoupling of various parameters which are conventionally required to be related.

[0071] It should be noted that a significant parameter is the response of the interconnect and seal to the clamping compressive load which must be applied to the fuel cell stack as schematically illustrated in Figure 1.

[0072] Figure 1 shows a compressive load applied to the top and bottom of assembly 10 which compressive load is advantageously selected to provide for sufficient interconnect bonding and sufficiently reduced leakage in the seals while nevertheless allowing micro-sliding in the seal area to relieve thermal mismatch stresses and to minimize compressive creep of the interconnects.

[0073] From a manufacturing standpoint, the system of the present invention provides for cells and interconnects having less stringent dimensional tolerances since the interconnect provides out-of-plane compliance and, therefore, increased dimensional freedom. Further, the provision of fixed thickness rail/spacers 44 and compression stops 50 ensures decoupling of the sealing and interconnection requirements and therefore provides substantial flexibility for building stacks that are based upon stable and compatible materials.

[0074] It should of course be appreciated that in accordance with the present invention, an interconnect superstructure and compliant seal assembly have been provided which advantageously allow for reduced stringency in tolerances in manufacture and assembly of solid oxide fuel cell stacks, and further which reduce the stresses conveyed between various components of the stack, thereby advantageously decoupling different design concerns of the stack and allowing selection of materials to provide long stack life.

[0075] It is to be understood that the invention is not limited to the illustrations described and shown herein, which are deemed to be merely illustrative of the best modes of carrying out the invention, and which are susceptible of modification of form, size, arrangement of parts and details of operation. The invention rather is intended to encompass all such modifications which are within its spirit and scope.